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Multidisciplinary Optimization Branch Experience Using iSIGHT Software

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Abstract

The Multidisciplinary Optimization (MDO) Branch at NASA Langley Research Center is investigating frameworks for supporting multidisciplinary analysis and optimization research. An optimization framework can improve the design process while reducing time and costs. A framework provides software and system services to integrate computational tasks and allows the researcher to concentrate more on the application and less on the programming details. A framework also provides a common working environment and a full range of optimization tools, and so increases the productivity of multidisciplinary research teams. Finally, a framework enables staff members to develop applications for use by disciplinary experts in other organizations.

Since the release of version 4.0, the MDO Branch has gained experience with the iSIGHT framework developed by Engineous Software, Inc. This paper describes experiences with four aerospace applications: (1) reusable launch vehicle sizing, (2) aerospike nozzle design, (3) low-noise rotorcraft trajectories, and (4) acoustic liner design. All applications have been successfully tested using the iSIGHT framework, except for the aerospike nozzle problem, which is in progress. Brief overviews of each problem are provided. The problem descriptions include the number and type of disciplinary codes, as well as an estimate of the multidisciplinary analysis execution time. In addition, the optimization methods, objective functions, design variables, and design constraints are described for each problem. Discussions on the experience gained and lessons learned are provided for each problem. These discussions include the advantages and disadvantages of using the iSIGHT framework for each case as well as the ease of use of various advanced features. Potential areas of improvement are identified.

Introduction

The Multidisciplinary Optimization (MDO) Branch at NASA Langley Research Center is a group of mathematicians, engineers, and computer specialists who identify optimization opportunities and develop and demonstrate optimization methods. The goal of the branch is to provide next-generation design tools that increase design confidence and reduce design cycle time. Most of the branch projects involve using optimization and related techniques to improve air and space vehicle designs.

Table 1. Examples of MDO Branch research

Information science	Design-oriented analysis	MDO formulations	Management and culture
• Databases, data flow and standards • Optimization frameworks • Design space visualization	• Approximation management • Automatic differentiation • Parametric geometry models	• Decomposition and organization • Optimization methods and issues • Discrete or random variables	• Multidisciplinary team building • Configuration Management • Cost and benefits training

Branch research falls into four basic categories: information science and technology, design-oriented multidisciplinary analysis, optimization formulations and solution methods, and management and cultural issues. Table 1 summarizes some recent activities in each of these categories. Further details

are available on the MDO Branch Web site <http://fmad-www.larc.nasa.gov/mdob/MDOB/> and in reference 1.

The MDO Branch study of optimization frameworks in general and the iSIGHT[2] framework developed by Engineous Software, Inc., in particular has a multiyear history. Reference 3 describes the Framework for Interdisciplinary Design Optimization (FIDO) project, in which members of the current branch developed a framework to facilitate execution of multidisciplinary computations on a heterogeneous system of networked computers. Based on experience gained in the FIDO project, Salas and Townsend[4] developed requirements for the ideal MDO framework and compared four existing frameworks including iSIGHT and FIDO to this ideal. In a related research effort, Alexandrov and Kodiyalam used version 3.1 of the iSIGHT framework to solve a set of 10 benchmark MDO problems.[5] Although Alexandrov and Kodiyalam note the strengths and weaknesses of iSIGHT software, the emphasis in reference 5 is on comparing MDO methods in order to evaluate their performance. In the present paper, challenging MDO applications are considered in order to evaluate version 4.05 of the iSIGHT framework.

Table 2. Features of iSIGHT framework evaluated by MDO Branch

Program features	iSIGHT user manual	Chapter
farSIGHT		
• calculation block	Developer's Guide	3
• simulation code block	Developer's Guide	3
• NASTRAN interface block	Developer's Guide	3
• reusable component	Developer's Guide	3
• control flow specifications	Developer's Guide	3
• file parsing	Developer's Guide	4
foreSIGHT		
• approximation concepts	Designer's Guide	8
response surface method	Designer's Guide	8
Taylor series approximation	Designer's Guide	8
• optimization techniques	Designer's Guide	Appendix B
ADS - Method of Feasible Directions	Designer's Guide	Appendix B
DONLP - Sequential Quadratic Programming	Designer's Guide	Appendix B
CONMIN - Method of Feasible Directions	Designer's Guide	Appendix B
overSIGHT		
• history graphs	Designer's Guide	11
• custom tables	Designer's Guide	11
• database browser	Designer's Guide	11

The iSIGHT framework includes the Multidisciplinary Optimization Language (MDOL) for describing optimization problems and a graphical user interface (GUI) for creating and interpreting MDOL description files.[2,6] The GUI is composed of three separate programs: farSIGHT for creating description files, foreSIGHT for specifying the optimization plan, and overSIGHT for monitoring the

progress of an optimization task. Table 2 provides a list of the major iSIGHT features discussed in this paper and the chapter numbers in the iSIGHT user manuals where more information is available.

Aerospace Applications of iSIGHT

Applications of iSIGHT software have been made to four aerospace problems of interest to the MDO Branch. Table 3 contains a summary of the four applications in terms of their size and complexity. Notice the wide range in difficulty of the analysis tasks. For example, the trajectory optimization problem contains a single simulation code, which can be evaluated in about a second on a modern engineering workstation. By contrast, the launch vehicle sizing problem incorporates two simulation codes that must be iterated to find a consistent design. This iterative procedure becomes an analysis task in iSIGHT and requires about 90 minutes of CPU time.

The four applications are considered in order to evaluate the iSIGHT framework as a tool for MDO research. Various iSIGHT versions, including 4.0, 4.01, and 4.05, were available during the evaluations. All remarks apply to version 4.05 software and version 4.05 documentation unless otherwise noted.[2,6]

Table 3. Summary of aerospace applications

Application	Number of simulation codes	Number of design variables	Number of constraints	Estimated CPU time for analysis task
Launch vehicle sizing	2	2	1	90 minutes
Aerospike nozzle design	4	18	564	90 seconds
Trajectory optimization	1	5	7	1 second
Acoustic liner research	1	60	0	20 seconds

The first two MDO applications involve parts of the conceptual design process for a reusable launch vehicle (RLV) like the VentureStar.[7] An artist's conception of the VentureStar is shown in figure 1. In the first RLV application, the objective is to determine the minimum vehicle size necessary to carry the required payload into orbit. In the second RLV application, the aerospike nozzle for the rocket engine is designed. The other two MDO applications use optimization to reduce noise either by altering the landing operations of a vehicle or by redesigning the acoustic liner for the engine.

Launch Vehicle Sizing

The independent variables for RLV sizing are the propellant mass fraction and the engine-thrust-to-vehicle-weight ratio (thrust/weight). Two simulation codes, CONSIZ[8] and POST[9], are used to determine the gross liftoff weight (GLOW) of the vehicle. CONSIZ calculates the weight of the vehicle based on the independent variables and the mass ratio to orbit (GLOW/weight-into-orbit). For example, given the mass ratios and thrust/weight, the volume of the liquid hydrogen and the liquid oxygen tanks (see fig. 2) can be calculated. Given these fuel tank volumes, the weight of the propellant and engines can be estimated and the vehicle GLOW can be determined. Given the weight estimates from CONSIZ, POST optimizes the trajectory of the vehicle and maximizes the payload weight to orbit. For a small change in independent variables, it takes about three iterations through the simulation codes for the masses to converge (i.e., for the mass ratio to orbit used by CONSIZ to be consistent with the payload weight returned by POST).

The RLV sizing problem requires a two-level analysis task, shown in figure 3. Figure 3a shows the farSIGHT display for the lower level task. On the lower level, the two simulation code blocks, CONSIZ and POST, are joined to calculation blocks that perform pre- and post-processing. On the upper level task, shown in figure 3b, a "while-loop" is used to repeat the lower level task a fixed

number of times. This flow diagram appears to be complex, but it was very easy to implement with the iSIGHT framework. A preliminary version was operational in one day. Moreover, the graphical representation shown in figure 3 was helpful during discussions with design team members (i.e., with members of the broader launch vehicle design group who were not involved in implementation of this particular design study).

The RLV sizing problem has been solved by using the CONMIN optimization technique, one of the options available in the foreSIGHT program. This RLV sizing procedure successfully predicted the overall size of the VentureStar vehicle needed to lift a full payload. The design discovered with iSIGHT software has essentially the same vehicle size as designs produced by experienced analysts using manual "cut and try" methods.

The RLV sizing application exposed both strengths and weaknesses in the current versions of iSIGHT software when used to optimize a complicated multidisciplinary analysis task. Although the analysis task was constructed in about a day, it took several weeks before it was fine tuned enough to furnish useful design information. The CONSIZ/POST iteration proved to be very sensitive to solution approach. Fortunately, the MDO Branch had advice from an analyst who has solved many similar problems, and thus they were able to capture his knowledge in the iSIGHT two-level analysis task. Once the lower level was operational, it took some experimentation to determine the maximum number of iterations that would provide adequate results. A better procedure would have been to repeat the lower level task until some convergence test on mass ratio to orbit was met, but version 4.05 of farSIGHT software does not provide a convenient mechanism for such a conditional loop. Furthermore, the lower level task converges more quickly and reliably given a good initial guess at the trajectory parameters that are inputs to POST. Because the analysis task is executed many times, it would be advantageous to save the results of previous executions and use those to predict a good initial guess. Again, no mechanism in farSIGHT software appears to provide this capability; however, UNIX scripts were developed to provide this "warm-start" capability, and these scripts were included in the two-level analysis task.

Aerospike Nozzle Design

The linear aerospike rocket engine is the propulsion system used for the X-33 and proposed for the VentureStar reusable launch vehicle.[7] The MDO Branch has developed a linear aerospike rocket nozzle model that consists of coupled aerodynamics and structural analyses. This model was used to demonstrate the benefits of MDO for engine design and to assess performance of various MDO approaches.[10]

The aerospike nozzle multidisciplinary analysis (see figs. 4 and 5) consists of three major parts: aerodynamic analysis, structural analysis, and GLOW determination. The aerodynamic analysis includes a detailed computational fluid dynamics (CFD) model and an approximate base-flow model. The aerodynamic analysis computes the engine thrust, the engine ISP (specific impulse), and the static loading on the nozzle structure as a function of the design variables that define the aerospike nozzle contour. The structural finite-element model (FEM) is generated based on geometric and structural design variables. The FEM analysis calculates the weight of a nozzle module. The FEM analysis also computes the stresses, displacements, and buckling responses, which are used to define the structural constraints. Estimates on vehicle GLOW are then determined by using the ISP and thrust/weight values.

The aerospike nozzle MDO problem described in reference 10 and pictured in figure 5 was originally implemented as a distributed FORTRAN program independent of the iSIGHT framework. Table 3 displays size and complexity information for this problem. The CONMIN optimization code[11] was included as part of this program and was used to minimize GLOW subject to the structural constraints. Each invocation of the multidisciplinary analysis produces the objective and constraints for the CONMIN program. Some portions of the analysis were implemented as subroutines, while other portions were separate programs or scripts invoked from the FORTRAN program through

system calls. The structural analysis was computed on a machine remote from the rest of the computation.

The conversion of the original aerospike nozzle MDO problem for the iSIGHT implementation was approached in the following manner. The original implementation was analyzed to separate the software pieces according to discipline functions. Through this analysis, the iSIGHT tasks, simulation blocks, and calculation blocks were defined. A hierarchical task structure was defined for the problem. The upper level task is called Aerospike1, which includes three tasks: Thrust1 (aerodynamic analysis), Weight2 (FEM analysis), and Glow3 (gross liftoff weight estimation). These lower level tasks were developed separately and defined as components with the farSIGHT reusable component feature. An advantage of this feature is that the Aerospike1 task may be easily assembled by selecting the various components, without cutting and pasting MDOL description files.

The Thrust1 task is defined with one calculation block and two simulation blocks. Eighteen parameters are defined in the Thrust1 task: eight inputs, seven outputs, and three auxiliary variables. The Weight2 task is the most complicated and is described below. The Glow3 task contains one calculation block and one simulation block. Eight parameters are defined in the Glow3 task: four inputs and four outputs. An advantage in defining these disciplinary analyses as separate tasks is that it provides a convenient way to perform both single disciplinary and multidisciplinary optimizations. For example, the Thrust1 task was used to optimize the aerodynamic design variables for maximum thrust by using the CONMIN optimization technique available in the foreSIGHT program. These results were compared to earlier aerodynamic optimizations to verify that the same results were produced by the CONMIN technique both inside and outside the iSIGHT framework.

The Weight2 task uses MSC/NASTRAN software, a product of MacNeal-Schwendler Corp., to perform the FEM structural analysis.[12] The preferred approach has been to select a NASTRAN block available in the farSIGHT program. Difficulties with this approach started with a need to transfer more than the iSIGHT limit of ten values of a specified response array. To overcome this limitation, the structural optimization problem was changed to have several design regions in which the largest five responses were of interest. A second problem arose with the failure of farSIGHT software to parse NASTRAN input in the "Large Field Format." This problem forced the use of single precision data transfers from iSIGHT software to NASTRAN software. A third problem occurred when iSIGHT software failed to transfer DRESP2 responses from the NASTRAN output file. These DRESP2 entries use the NASTRAN software's DEQATN function to constrain structural design variables. These constraints were moved into a calculation block. A fourth problem arose due to the critical buckling ratio calculation. For numerical stability and robustness, the critical buckling ratio constraint is formulated as two eigenvalue problems. Unfortunately, iSIGHT software only allows for transferring the results of a single eigenvalue problem. To overcome this difficulty requires either using the NASTRAN software's DEQATN function or formulating the constraint in another calculation block with the eigenvalues from a single NASTRAN analysis. When using a calculation block, the user is required to supply the sensitivity of the responses with respect to the design variables. The procedures for extracting sensitivities from the NASTRAN database and using these sensitivities in the calculation block to calculate the response sensitivities with the chain rule have yet to be identified.

The alternative approach to implementing the Weight2 task is to treat MSC/NASTRAN software as any other simulation code. In this case, the Weight2 task consists of one Unix script with several preprocessing programs and the MSC/NASTRAN program. The extensive text output file produced by a NASTRAN structural analysis is parsed to extract the 564 responses. This method uses more disk space and CPU time than the preferred method, which reads the NASTRAN database directly and produces no text output file. It is also less accurate, because the structural response sensitivities are estimated rather than calculated by MSC/NASTRAN software.

Once the Weight2 task has been defined, the Aerospike1 upper level task may be completed. The original implementation of the aerospike nozzle problem computes system derivatives by using finite differences (i.e., no sensitivities are computed by MSC/NASTRAN software). The first aerospike implementation in the iSIGHT framework will likely use this same approach. However, to avoid the

potential inefficiencies described in the preceding paragraph, the preferred approach is to use the farSIGHT program's NASTRAN block. The two remaining questions are how to convert the aerodynamic pressures from the Thrust1 task into structural loads in the Weight2 task and how to calculate the derivatives of the structural responses with respect to the aerodynamic pressures.

Although the aerospike implementation is not yet complete, the iSIGHT framework has many obvious advantages for solving large MDO problems. It provides a method for connecting several simulation codes together without changing any of the codes. Unlike the iSIGHT framework implementation, the original approach to the aerospike nozzle implementation, where one large program is defined, does not lend itself to experimenting with the single discipline analyses and optimizations, nor the integrated analysis and optimization. Not only does this iSIGHT framework feature make it quick and easy for the system developer; it also aids the disciplinary experts who need to run their codes in stand-alone mode as well as integrated into the system.

The iSIGHT framework also provides flexible tools for visually monitoring the operation of the complex system and provides database and description file tools for recording the history of the project. In the original implementation, a custom postprocessor was written to extract the values of interest from the CONMIN output. The iSIGHT software removes this burden; however, there is some question whether the database browser and graphical monitoring software can process the huge amounts of data that the aerospike MDO problem will produce. Finally, iSIGHT allows the system analysis development to be separated from the choice of optimization method and problem formulation. Because the foreSIGHT program makes it easy to change the set of design variables or the optimization method, these important decisions can be revisited as the project unfolds.

Trajectory Optimization

The third application uses the iSIGHT framework to adjust rotorcraft trajectories in order to reduce community noise. The initial optimization problem involves a single simulation code block and only five design variables and seven constraints. The application demonstrates that rapid prototyping tools and a variety of optimization and approximation methods are essential features of the iSIGHT framework.

The MDO Branch investigated trajectory optimization at the request of the Langley Rotorcraft and Short-Haul Civil Tiltrotor Manager. The rotorcraft manager desired a trajectory-planning tool that could be used by a team of acoustic specialists to design rotorcraft flight tests. The ultimate goal was to predict noise impact on communities and to design community-specific flight profiles.

The trajectory analysis task predicts noise exposure on the ground due to rotorcraft landing operations. The primary input and output variables are illustrated in figure 6. The landing trajectory is composed of several flight segments. Each flight segment can be described by an initial altitude, airspeed, and glide slope. In the case of tiltrotor aircraft, such as the XV-15 (see photo in fig. 7), the nacelle angle is a fourth degree of freedom that varies with the flight segment. The noise impact is predicted as a Sound Exposure Level (SEL) for a certain location on the ground. Alternately, the noise impact is reported as the number of acres of land that are exposed to unacceptable noise levels. Preliminary flight tests reported in reference 13 indicate that the noise exposure due to XV-15 landing operations is highly dependent on the flight profile selected by the pilot. For example, figure 8 compares the SELs for 16 different landings of an XV-15.

As a proof of concept, the MDO Branch agreed to use the Rotorcraft Noise Module[14] (RNM) to predict XV-15 noise footprints and to use iSIGHT software as an optimization framework. Sample input and output files for RNM were provided and potential objectives and design variables were discussed. The rotorcraft manager gave the branch one week to create a proposal including time and manpower estimates.

At the end of the first week, iSIGHT software had produced preliminary optimization results from RNM noise predictions. For these results, the initial airspeed, glide slope, and nacelle angle were the three design variables, and the SEL predictions for three locations along the centerline were averaged

to form an objective function. Although the rotorcraft manager was impressed with these rapid results, he concluded that the MDO Branch would require guidance in order to formulate the optimization problem correctly.

The iSIGHT framework was instrumental in facilitating the interaction between acoustic engineers and optimization experts. The engineers requested additional design variables and constraints in order to define approach profiles that are acceptable to pilots and comfortable for passengers. The engineers quickly learned how to activate and deactivate potential design variables and constraints with the foreSIGHT program. They liked the flexibility of monitoring the various inputs and outputs with the overSIGHT program and the ability to maintain a historical database of their work. They especially liked the fact that the RNM input file is updated during the optimization task. Having the input file that corresponds to the minimum noise design allowed the engineers to rerun the RNM code with numerous options for graphically postprocessing the final trajectory. As a result of their experimentation, four candidate XV-15 noise abatement approach profiles were developed. These profiles received further evaluation in the NASA Ames Vertical Motion Simulator and are candidates for the XV-15 Noise Abatement Approaches flight experiment scheduled for October 1999.

While the acoustic engineers formulated the problem, the optimization experts experimented with solution methods. The trajectory optimization problem has several challenging aspects. First, the RNM code was provided as an executable. Thus, the contents of the output file cannot be changed except by modifying the input file. Second, RNM noise predictions are remarkably accurate because they are based on high quality measured data. Because accuracy is important, the RNM code will not predict noise levels unless there is sufficient data in the database. Thus, for some combinations of design variables, the RNM code would output a warning message rather than a noise prediction. Third, the RNM code uses several interpolation methods to extract data from its database. Some interpolations use the closest value in the database, while others use linear or nonlinear fit through several data points. Thus, RNM software produces accurate noise predictions that are not smooth and cannot be used to calculate local sensitivity derivatives.

Tools provided by version 4.05 of the iSIGHT software overcame all the challenges presented by the trajectory optimization problem. Input and output file parsing tools in the farSIGHT program were flexible enough to handle the file formats expected by the RNM code. Calculation blocks were used in two ways: they created a penalized objective function value whenever the RNM code failed to predict SEL, and they created constraints on the flight profile so that unsafe landing operations were disallowed. Response surface method approximations available in the foreSIGHT program were especially valuable. The approximation method provided accurate sensitivity derivatives and reduced the total number of analysis task executions. The combination of response surface method and CONMIN optimization method worked so well that no other methods were considered.

Acoustic Liner Research

The final application of the iSIGHT framework enabled fundamental research in acoustic liner concepts. This research is important because all commercial aircraft use acoustic liners to reduce jet engine noise. Unfortunately, the effectiveness of the liners is limited because of weight and packaging constraints. One idea for designing acoustic liners is to make them from multiple segments, each of which has a different thickness and different material properties. In this way, the liner might be designed to reduce noise at the frequencies that are especially objectionable to passengers and flight crews without adding weight or thickness when compared to conventional liners.

The acoustic liner project was frustrating for the optimization experts because the noise prediction code was constantly changing. The code was being improved and validated at the same time that the optimization methods were being tested. Unusual optimization results often pointed to problem areas in the noise prediction code, and revised codes sometimes required new optimization strategies. This research effort is on going, and no acoustic liner results are available at this time. However, the project was an excellent test of the versatility of the iSIGHT framework.

The acoustic liner optimization problem is challenging because of the large number of potential design variables and because of the multimodal nature of the objective function. Acoustic optimization problems are inherently multimodal because the predicted noise changes dramatically when any liner thickness approaches any multiple of the characteristic wavelength. Thus, the optimization method must include an efficient global search to identify promising regions of the design space, followed by a tightly constrained local search to converge to a single solution. Several optimization methods available in the foreSIGHT program, such as DONLP and ADS methods provided the necessary flexibility to solve acoustic problems.

Several advanced iSIGHT software tools were used to solve the acoustic liner problem. Array processing tools were especially important because the number of segments and the number of material properties per segment were initially unspecified. This problem characteristic led to a strategy where the optimization methods were tested with a small number of design variables, but each design variable was described by an array whose length was adjustable. This strategy allowed experimentation with numerous optimization and approximation methods and provided solutions in a few hours rather than a few days. Based on promising results from computationally inexpensive problems, problems with 60 design variables (i.e., thirty segments, with thickness and impedance as design variables for each segment) were solved.

Solving the acoustic liner optimization problems revealed that the iSIGHT array processing tools in version 4.05 are quite powerful, but not completely automated. The farSIGHT GUI was used to set up about 90 percent of the analysis task, and the foreSIGHT GUI was used to specify the optimization plan, but manual editing of the MDOL description file was required. Although there are excellent examples of array processing in the *iSIGHT Developer's Guide*,[6] the MDO Branch staff required assistance from the iSIGHT technical support staff in order to create an MDOL file that operated correctly.

Concluding Remarks

The Multidisciplinary Optimization Branch at NASA Langley Research Center has been using the iSIGHT framework (versions 4.0 through 4.05) for about one year. This paper documents the experience of the four authors and does not constitute a NASA endorsement or evaluation of the iSIGHT software. During the past year, four applications of the optimization framework were evaluated. The aerospike nozzle design project is representative of the primary research tasks of our branch, the reusable launch vehicle sizing project is representative of branch contributions to NASA system analysis activities, and the acoustics projects (the rotorcraft trajectory optimization and acoustic liner optimization) represent research efforts of other organizations that requested help from our optimization experts.

The evaluation of iSIGHT optimization framework identified minor weaknesses in the Engineous Software, Inc. commercial software package that can be addressed in future versions of the code. These weaknesses can be overcome through manual edits to the MDOL description files. For example, array processing is very useful when the number of design variables or constraints is either large or adjustable. Yet, MDO Branch evaluators failed to implement arrays in the acoustic liner problem without help from the MDOL experts. Similarly, the tools for integrating several simulation codes into a complicated analysis task are not quite ready for nonexpert users of iSIGHT framework. In fact, it is doubtful that disciplinary experts with little optimization training will be able to use iSIGHT framework at all without help from both MDOL and optimization experts.

Inevitably, during our extended use of iSIGHT software, the MDO Branch discovered some features that were quite unsatisfactory. At the top of the list is the MSC/NASTRAN software interface; this interface is far from automatic and is inadequate to solve the challenging structural design problems of interest to the MDO Branch. To date we have been unsuccessful in our use of the MSC/NASTRAN structural analysis code inside the iSIGHT framework. Hopefully the deficiencies uncovered will be addressed by Engineous Software, Inc. The other features that have significant

limitations involve control flow specifications that use the farSIGHT program for analysis task development. For multidisciplinary research where several simulation code blocks must be iterated using logical tests and updated input files, the present version of farSIGHT software is inadequate.

The evaluation of the iSIGHT framework also identified strengths. The package contains numerous optimization, approximation, and design-of-experiments tools. Branch members experimented with about half of the available methods and determined that no one of these methods would have been sufficient for solving all four applications. Moreover, the ability to easily switch from one method to an alternate method while solving a problem was extremely valuable.

The MDO Branch also discovered that iSIGHT software increases our ability to interact with our customers. A prototype optimization plan can be assembled in about one week. This prototype can be used to further define the optimization problem—for example, by adding constraints or modifying the objective function. The graphical displays can be used to monitor optimization histories and to explain the operation of complex analysis tasks. Finally, the iSIGHT software allows the optimization experts to develop optimization methods that the disciplinary experts can use and modify.

The benefits of this software are not free. The software licenses are somewhat expensive and additional seats are required as more projects are implemented in iSIGHT framework. For multidisciplinary projects, these costs mean that several organizations must be encouraged to purchase the software and new people must be trained in its use. There are hidden costs, such as system administration costs required to install and test new versions of the software, and hardware costs to maintain workstations on which the framework is available. Finally, there are computational overhead costs, such as the cost of parsing large input and output files and the costs of the iSIGHT framework functions. In our judgment, however, these costs are insignificant compared to the potential manpower savings.

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Figures

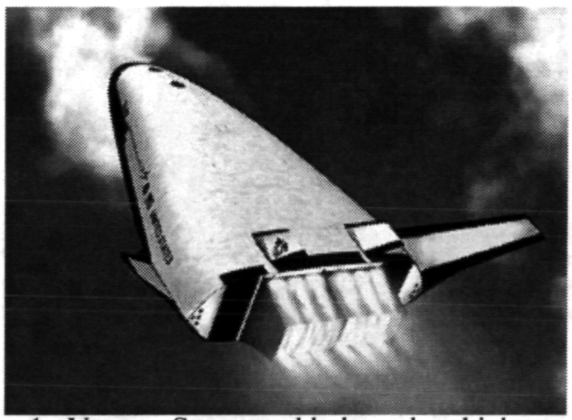


Figure 1. VentureStar reusable launch vehicle concept.

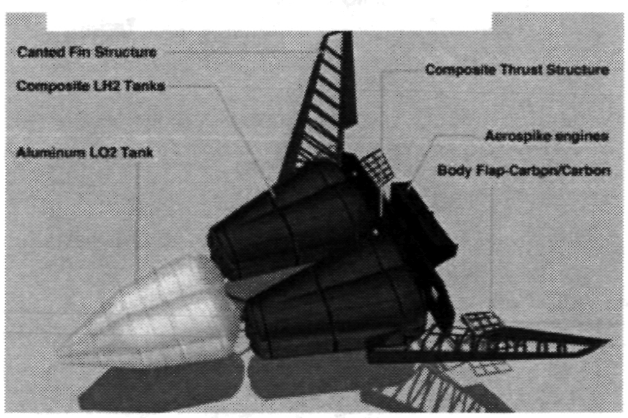
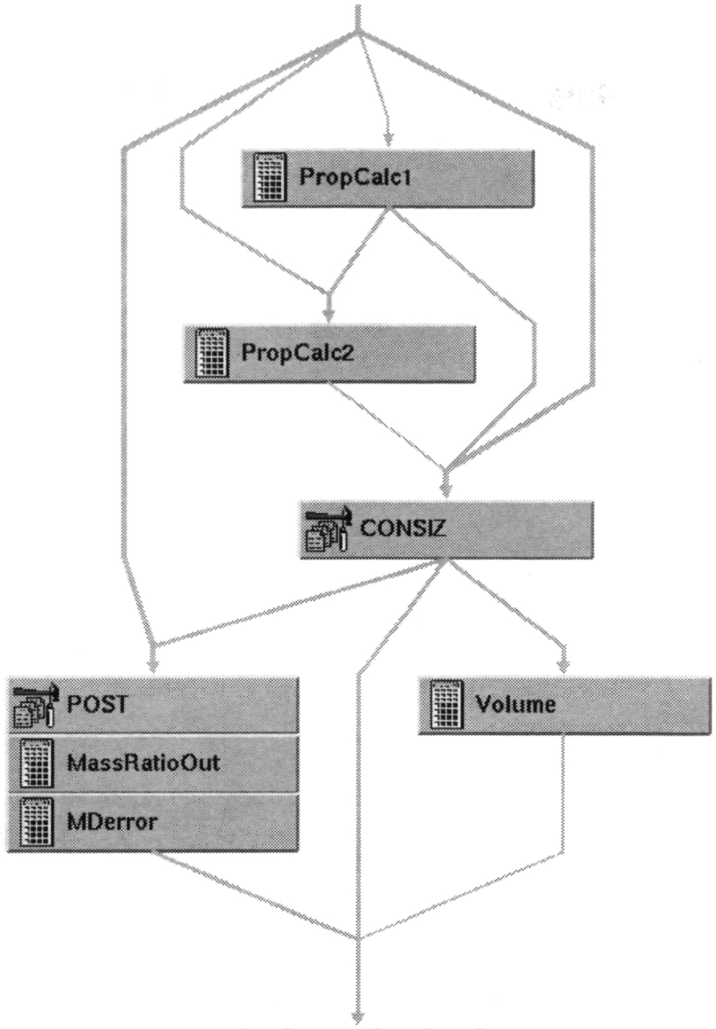
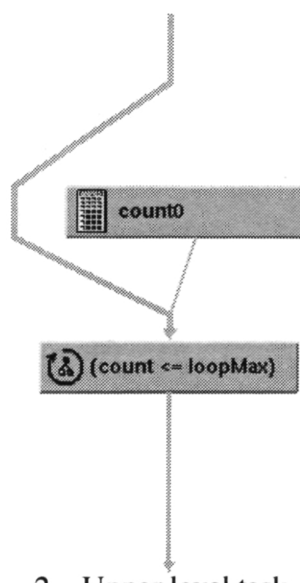


Figure 2. Conceptual design of RLV showing fuel tanks and aerospike nozzle.



1. Lower level task



2. Upper level task

Figure 3. Launch vehicle sizing analysis task.

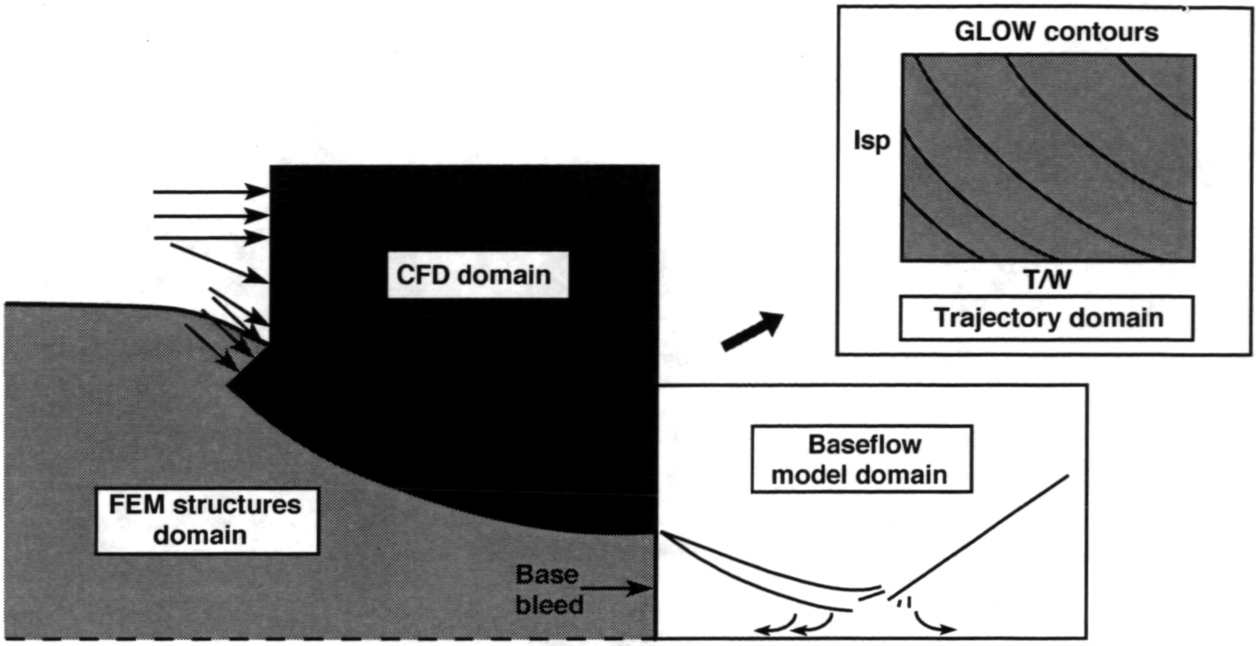


Figure 4. Multidisciplinary analysis for aerospike nozzle design.

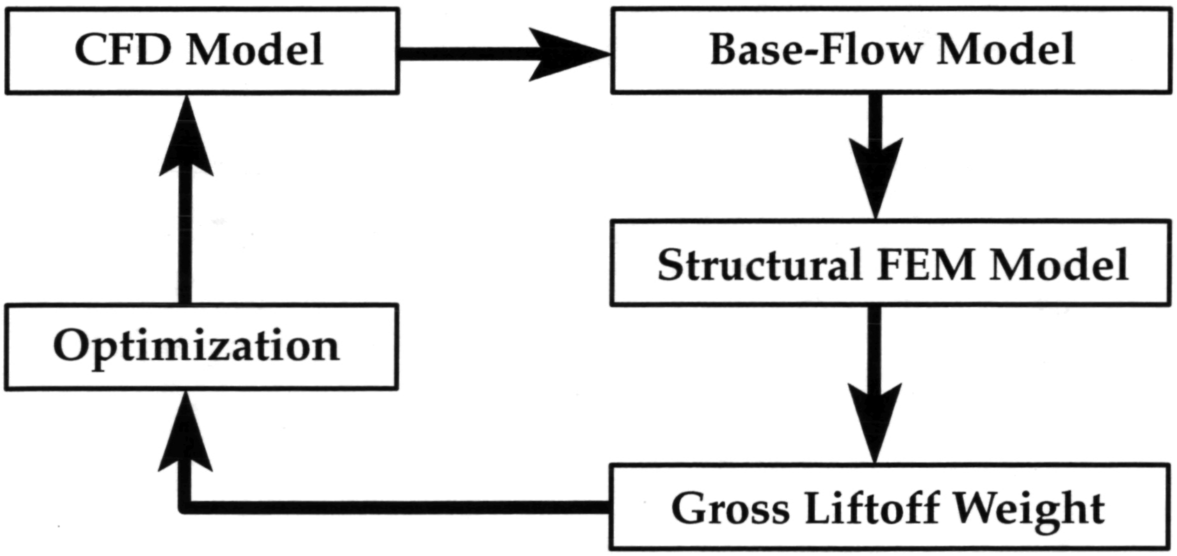


Figure 5. Data flow for multidisciplinary aerospike nozzle analysis.

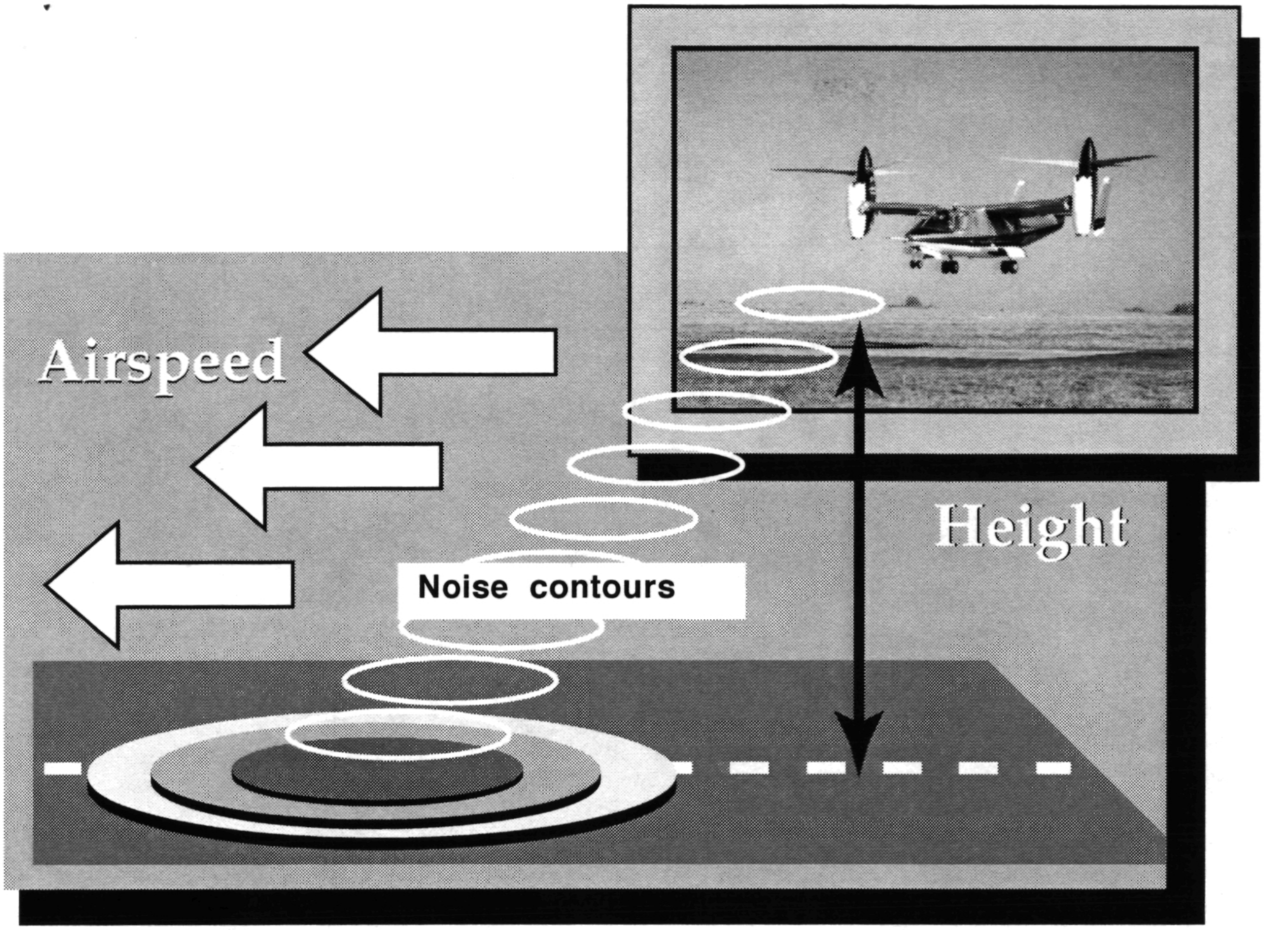


Figure 6. Rotorcraft trajectory optimization.

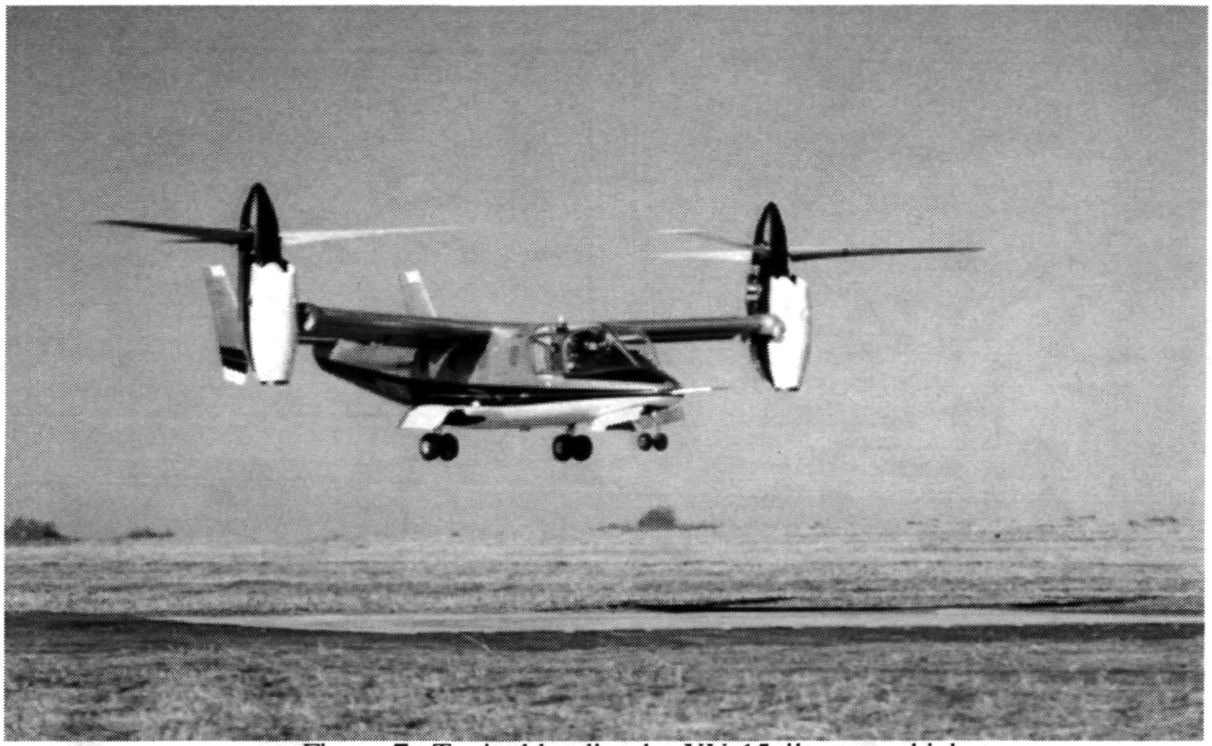


Figure 7. Typical landing by XV-15 tiltrotor vehicle.

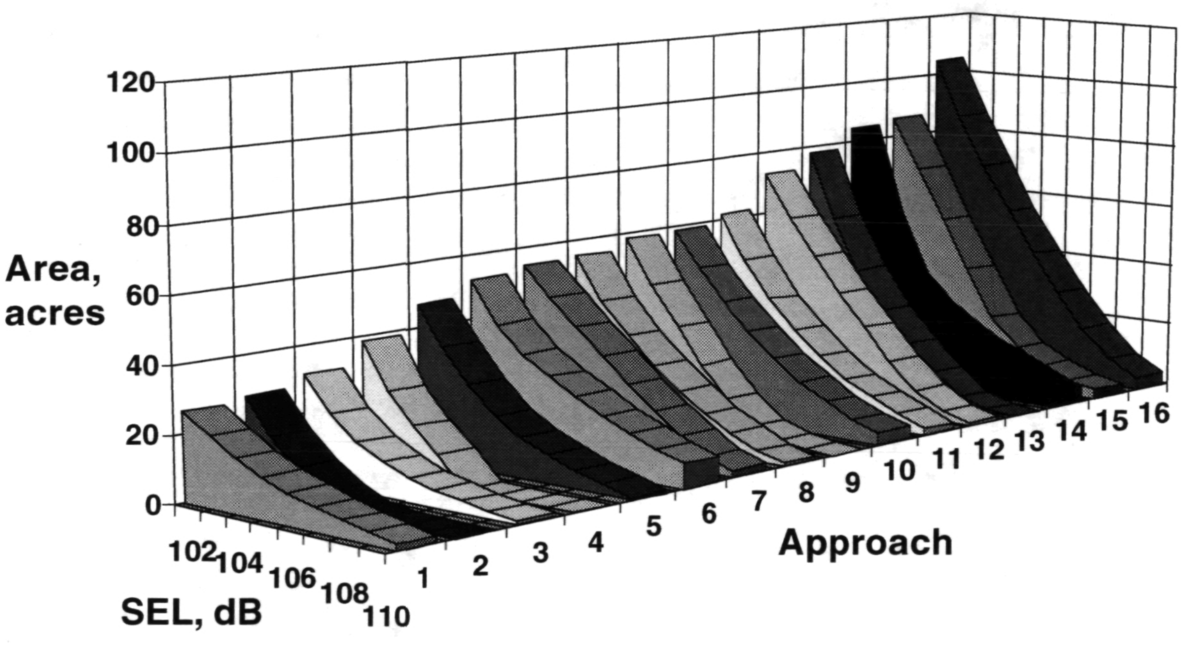


Figure 8. Noise levels for 16 different landing approaches.